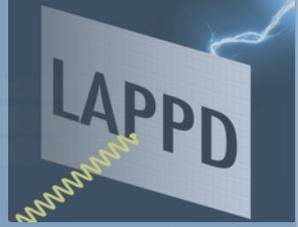




University of Chicago



Atomic Layer Deposition in HEP: Lessons and Opportunities

Matt Wetstein
University of Chicago/ANL

presenting work of

Jeff Elam and Anil Mane
Argonne National Laboratory, Material Science Division

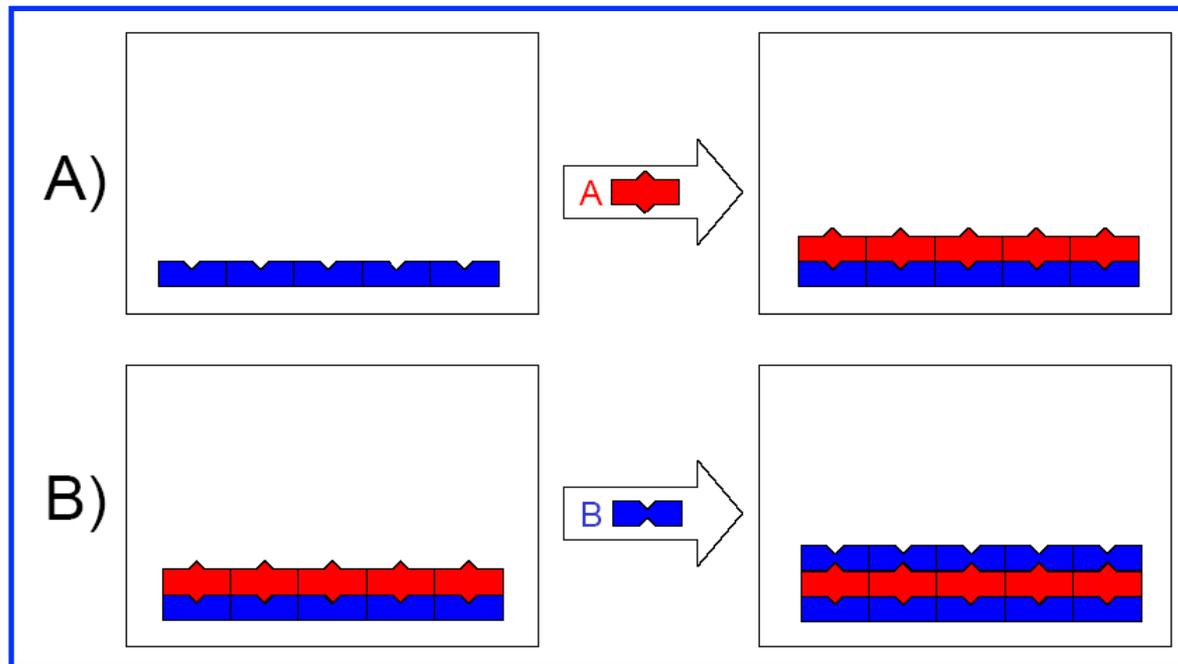
material borrowed heavily from
Mike Pellin
Argonne National Laboratory, Material Science Division

and on behalf of the Large Area Picosecond Photodetector (LAPPD) Collaboration

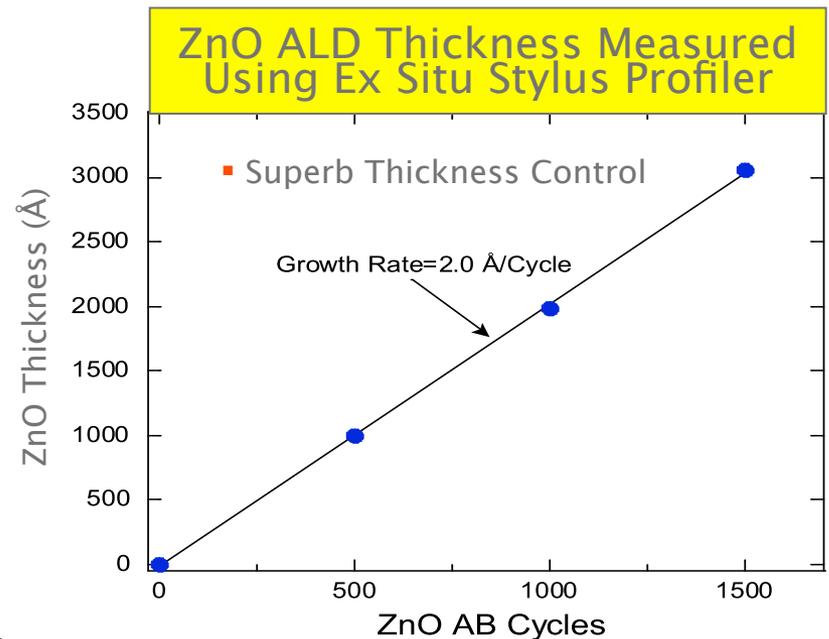
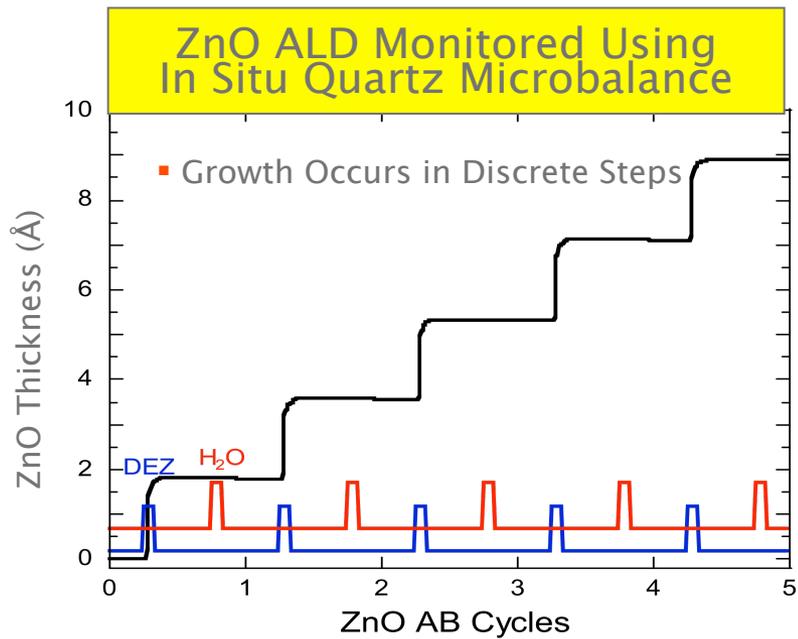
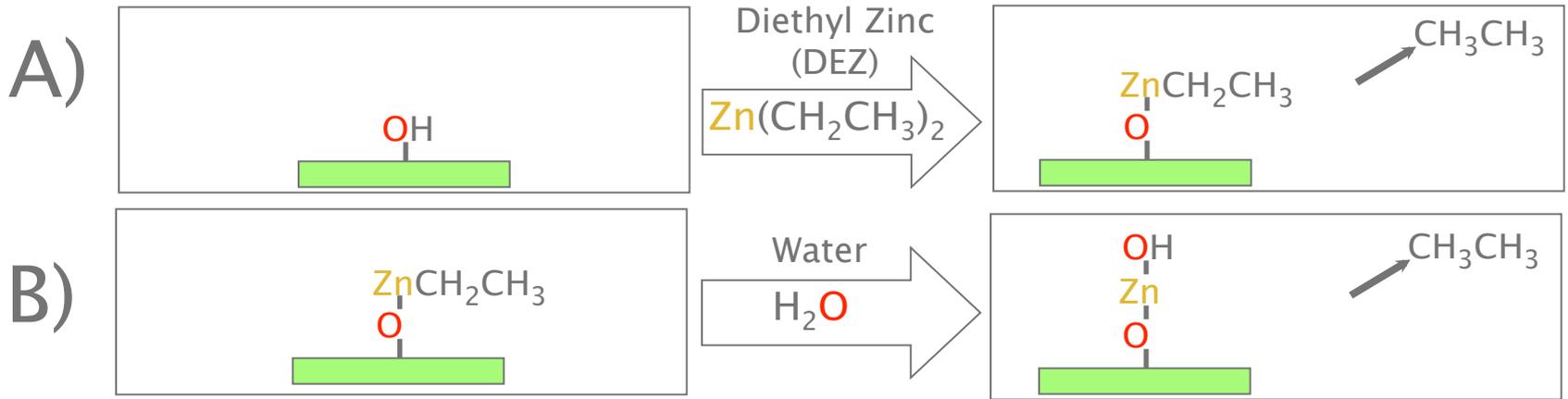
Snowmass on the Mississippi
Aug 2, 2013

What is Atomic Layer Deposition (ALD)?

Atomic Layer Deposition is a chemical vapor deposition technique based on the sequential application of two or more chemicals (precursors) that undergo self-limiting reactions with solid surfaces. This allows the application of materials, one atomic mono-layer at a time.



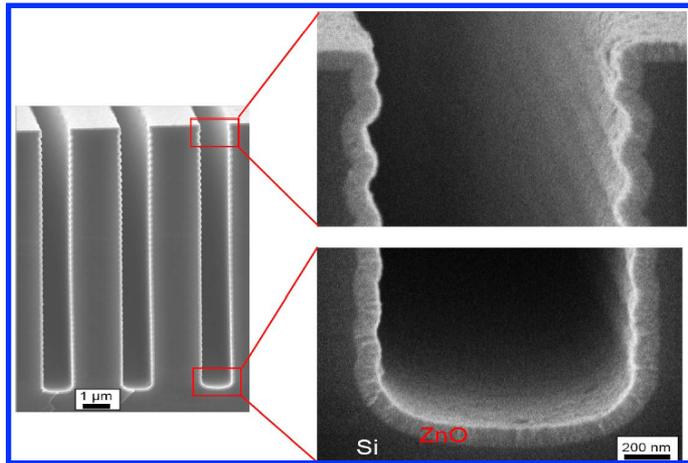
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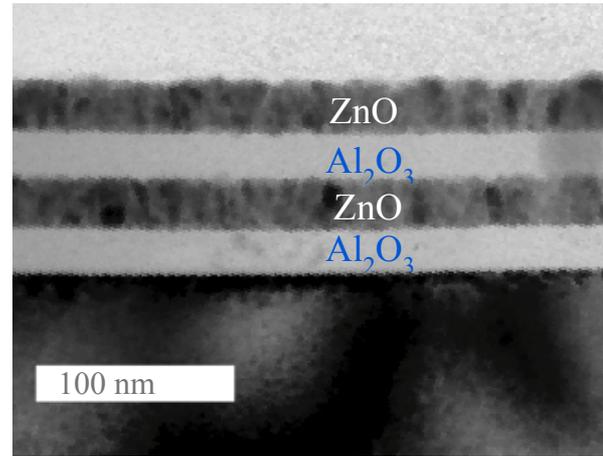
Pellin

What is Atomic Layer Deposition (ALD)?

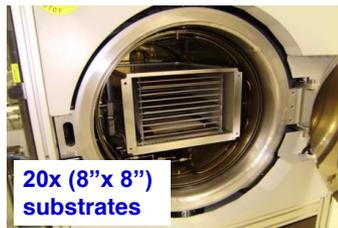
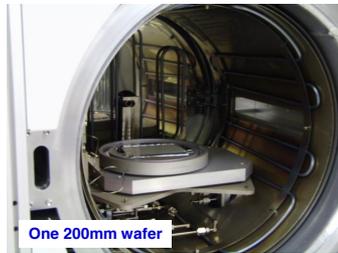
Conformal



Can produce hybrid, layered materials



Scalable



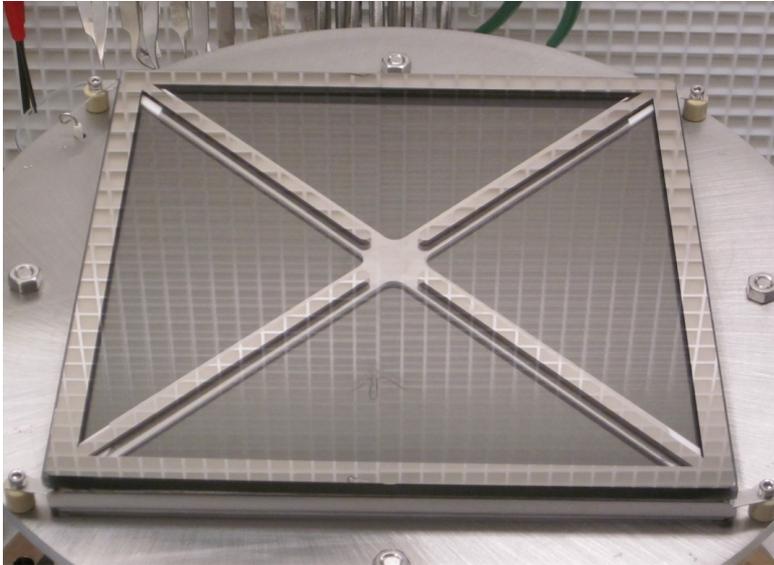
Compatible with a large number of elements and compounds

1 H Hydrogen 1.00794																	2 He Helium 4.002
3 Li Lithium 6.941	4 Be Beryllium 9.012182											5 B Boron 10.811	6 C Carbon 12.0107	7 N Nitrogen 14.00674	8 O Oxygen 15.9994	9 F Fluorine 18.9984032	10 Ne Neon 20.1797
11 Na Sodium 22.989770	12 Mg Magnesium 24.3050											13 Al Aluminum 26.981538	14 Si Silicon 28.0855	15 P Phosphorus 30.973761	16 S Sulfur 32.066	17 Cl Chlorine 35.4527	18 Ar Argon 39.948
19 K Potassium 39.0983	20 Ca Calcium 44.078	21 Sc Scandium 44.955910	22 Ti Titanium 47.88	23 V Vanadium 50.9415	24 Cr Chromium 51.9961	25 Mn Manganese 54.938044	26 Fe Iron 55.845	27 Co Cobalt 58.933200	28 Ni Nickel 58.6934	29 Cu Copper 63.546	30 Zn Zinc 65.39	31 Ga Gallium 69.723	32 Ge Germanium 72.64	33 As Arsenic 74.92160	34 Se Selenium 78.96	35 Br Bromine 79.904	36 Kr Krypton 83.80
37 Rb Rubidium 85.4678	38 Sr Strontium 87.62	39 Y Yttrium 88.90585	40 Zr Zirconium 91.224	41 Nb Niobium 92.90638	42 Mo Molybdenum 95.94	43 Tc Technetium 98	44 Ru Ruthenium 101.07	45 Rh Rhodium 102.90550	46 Pd Palladium 106.42	47 Ag Silver 107.8682	48 Cd Cadmium 112.411	49 In Indium 114.818	50 Sn Tin 118.710	51 Sb Antimony 121.760	52 Te Tellurium 127.60	53 I Iodine 126.90447	54 Xe Xenon 131.29
55 Cs Cesium 132.90545	56 Ba Barium 137.327	57 La Lanthanum 138.9055	58 Ce Cerium 140.12	59 Pr Praseodymium 140.90768	60 Nd Neodymium 144.24	61 Pm Promethium 144.9128	62 Sm Samarium 150.36	63 Eu Europium 151.964	64 Gd Gadolinium 157.25	65 Tb Terbium 158.92534	66 Dy Dysprosium 162.50	67 Ho Holmium 164.93032	68 Er Erbium 167.26	69 Tm Thulium 168.93421	70 Yb Ytterbium 173.04	71 Lu Lutetium 174.967	
87 Fr Francium 223	88 Ra Radium 226	89 Ac Actinium 227	90 Th Thorium 232.0377	91 Pa Protactinium 231.03688	92 U Uranium 238.02891	93 Np Neptunium 237	94 Pu Plutonium 244	95 Am Americium 243	96 Cm Curium 247	97 Bk Berkelium 247	98 Cf Californium 251	99 Es Einsteinium 252	100 Fm Fermium 257	101 Md Mendelevium 258	102 No Nobelium 259	103 Lr Lawrencium 262	

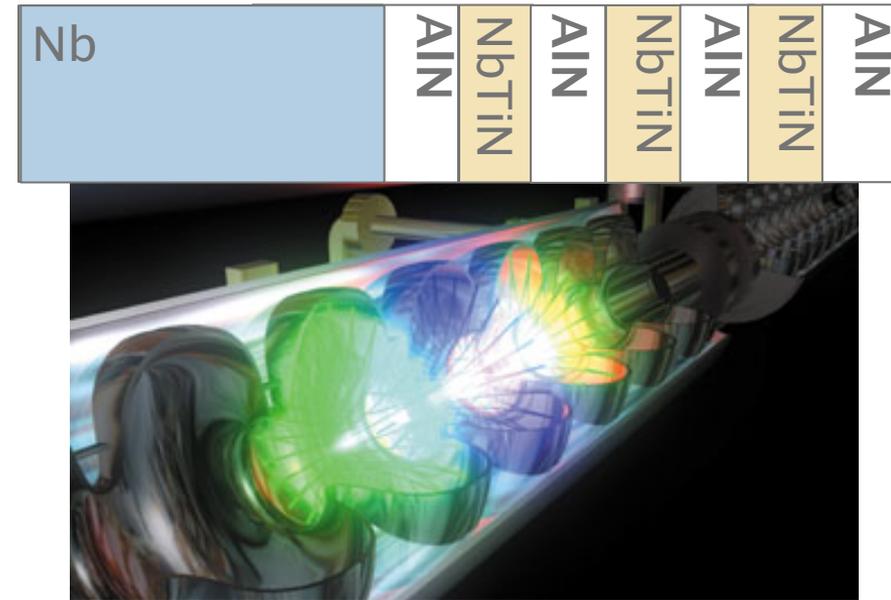
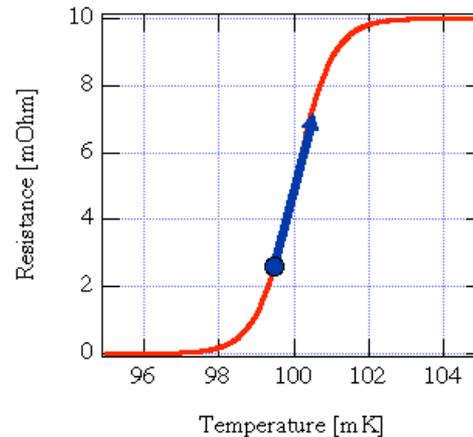
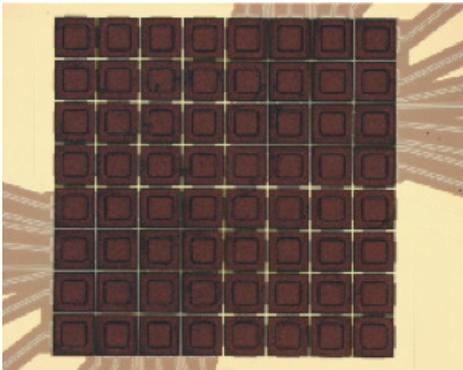
 Oxide
 Nitride
 Element
 S/Se/Te
 Ph/As
 C
 F
 Dopant

ALD is very useful for HEP!

Large Area Picosecond Photodetectors



Transition Edge Sensors



Superconducting RF cavities

- Layered structures raise the critical magnetic field at which vortex losses form.

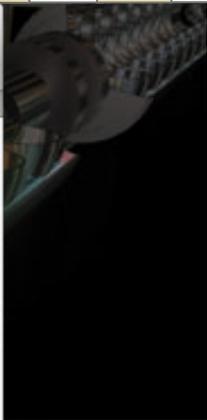


ALD is very useful for HEP!

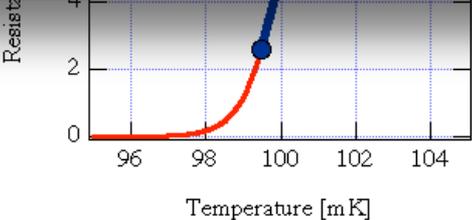
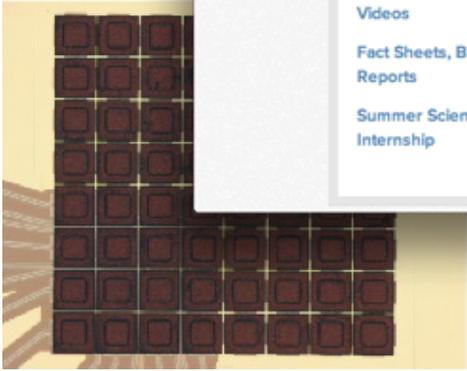
Large Area Picosecond Photodetectors



The screenshot shows a web browser displaying an article from the Argonne National Laboratory website. The article title is "Argonne claims four 2013 R&D 100 Awards" dated July 8, 2013. The article text states: "ARGONNE, Ill. — Four innovative technologies have won 2013 R&D 100 Awards, regarded as the 'Oscars of invention,' for the U.S. Department of Energy's Argonne National Laboratory. The awards recognize the top scientific and technological innovations of the past year as judged by a team of independent experts for R&D magazine. Argonne scientists have won 120 R&D 100 awards since they were first introduced in 1964. 'My sincere congratulations to the winners of this year's R&D 100 Awards,' said Energy Secretary Ernest Moniz. 'The scientists and engineers who developed these award-winning technologies at the cutting-edge facilities across our national labs are keeping Americans at the forefront of the innovation community and assuring our nation's economic competitiveness and national security.'" A photo of two scientists, Jeff Elam and Anil Mane, is included. The website navigation includes categories like ENERGY, ENVIRONMENT, SECURITY, USER FACILITIES, SCIENCE, and TECHNOLOGY.



activities
critical
EX



Snowmass – August, 2013



LAPPD Collaboration

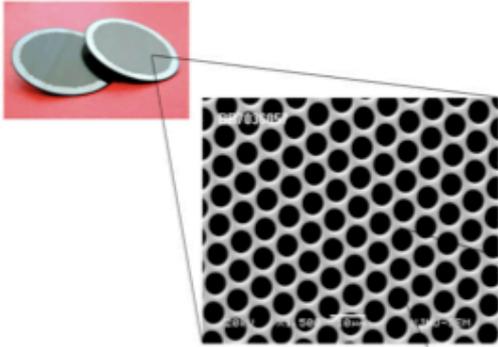
Reinventing the unit-cell of light-based neutrino detectors



- single pixel (poor spatial granularity)
- nanosecond time resolution
- bulky
- blown glass
- sensitive to magnetic fields

- millimeter-level spatial resolution
- <100 picosecond time resolution
- compact
- standard sheet glass
- operable in a magnetic field

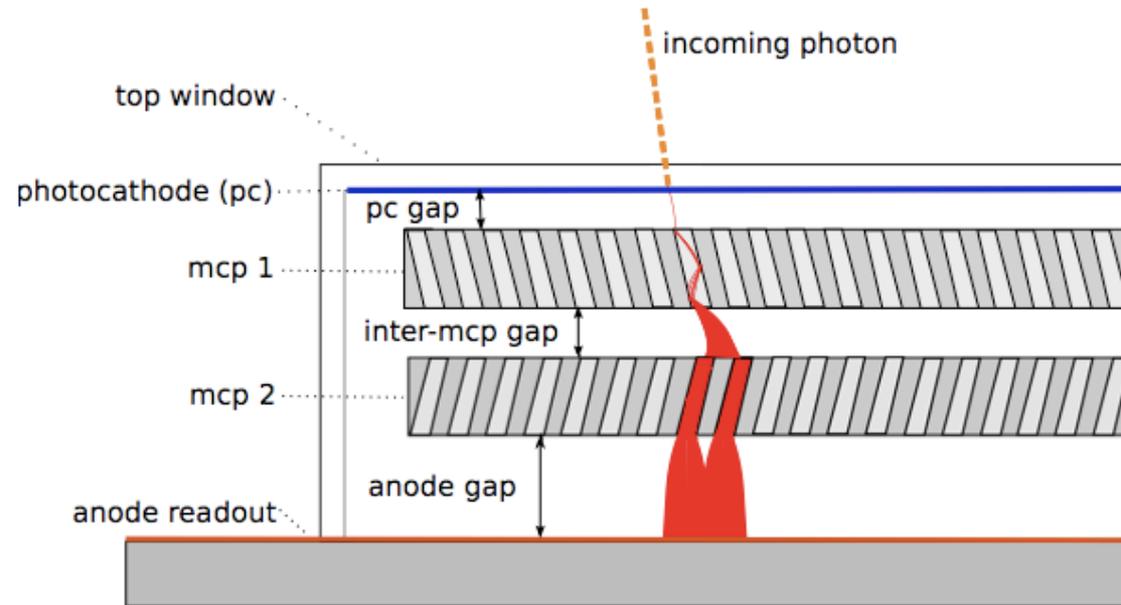
What is an MCP-PMT?



Microchannel Plate (MCP):

- a thin plate with microscopic (typically $<50 \mu\text{m}$) pores
- pores are optimized for secondary electron emission (SEE).
- Accelerating electrons accelerating across an electric potential strike the pore walls, initiating an avalanche of secondary electrons.

- An MCP-PMT is, sealed vacuum tube photodetector.
- Incoming light, incident on a photocathode can produce electrons by the photoelectric effect.
- Microchannel plates provide a gain stage, amplifying the electrical signal by a factor typically above 10^6 .
- Signal is collected on the anode



Key Elements of the LAPPD Detector

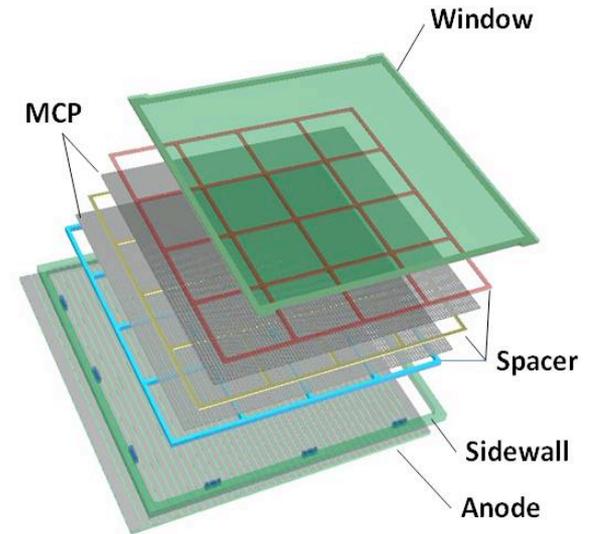
Glass body, minimal feedthroughs

MCPs made using atomic layer deposition (ALD).

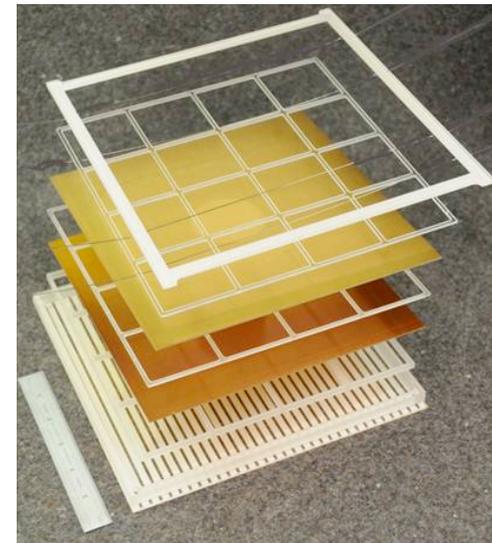
transmission line anode

fast and economical front-end electronics

large area, flat panel photocathodes

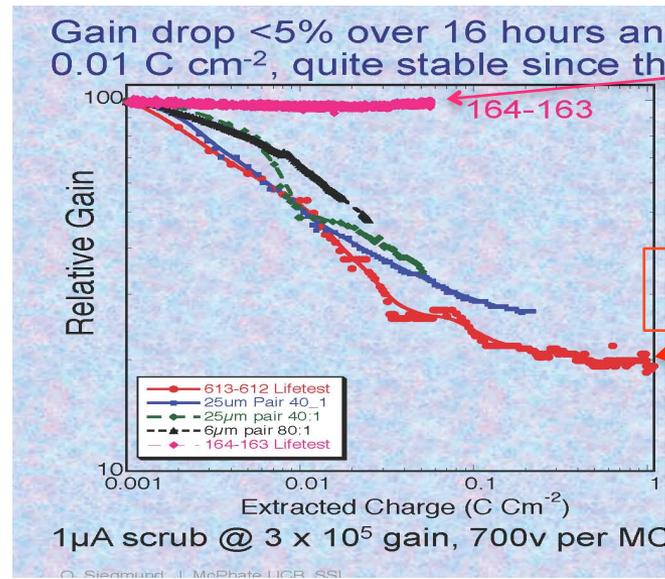


Design Drawing - September 2010



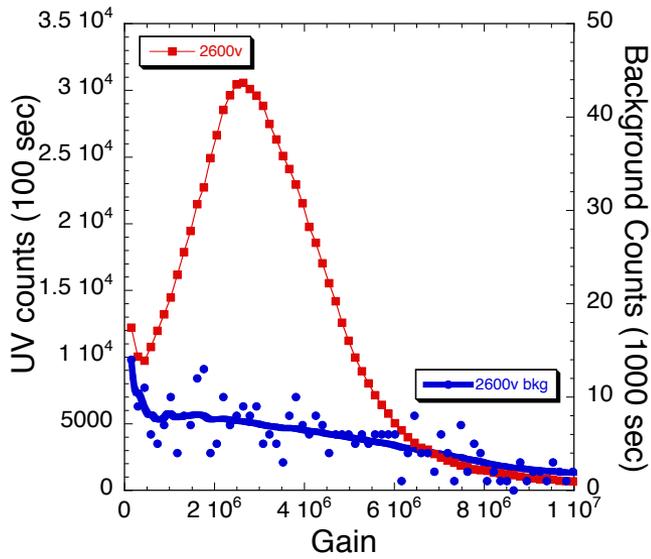
Actual Glass Parts - April 2012

The Wonders of Pure Materials



Measured ANL ALD-MCP behavior

Typical MCP behavior- long scrub-times



Lifetime of latest generation Microchannel Plate PMT's
A. Britting, W. Eyrich, A. Lehmann[†], F. Uhlig, and PANDA Cherenkov group

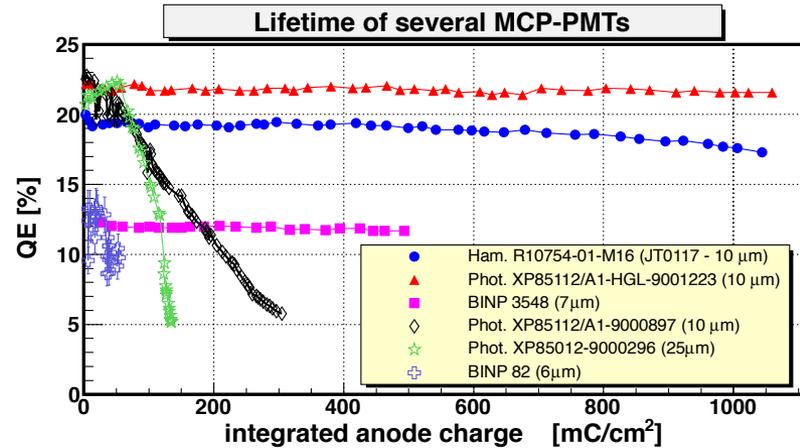
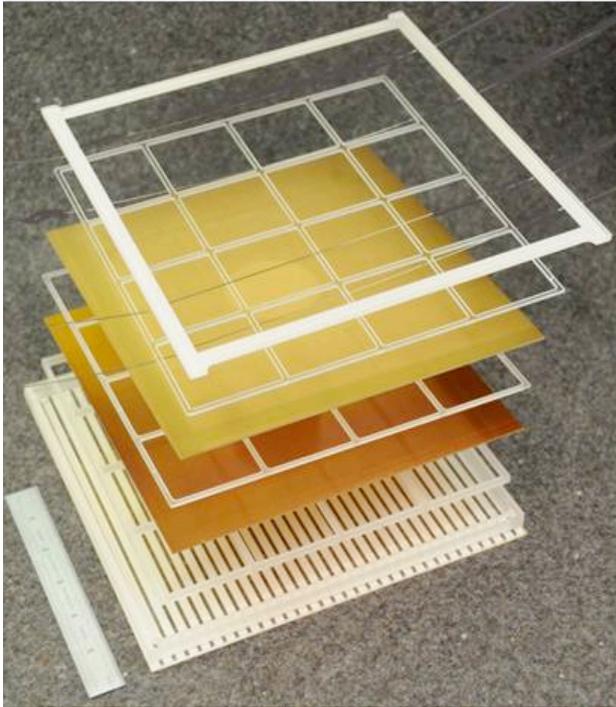


Figure 1: QE at 400 nm for old (open) and new generation (solid dots) MCP-PMTs as function of the anode charge.



LAPPD detectors:

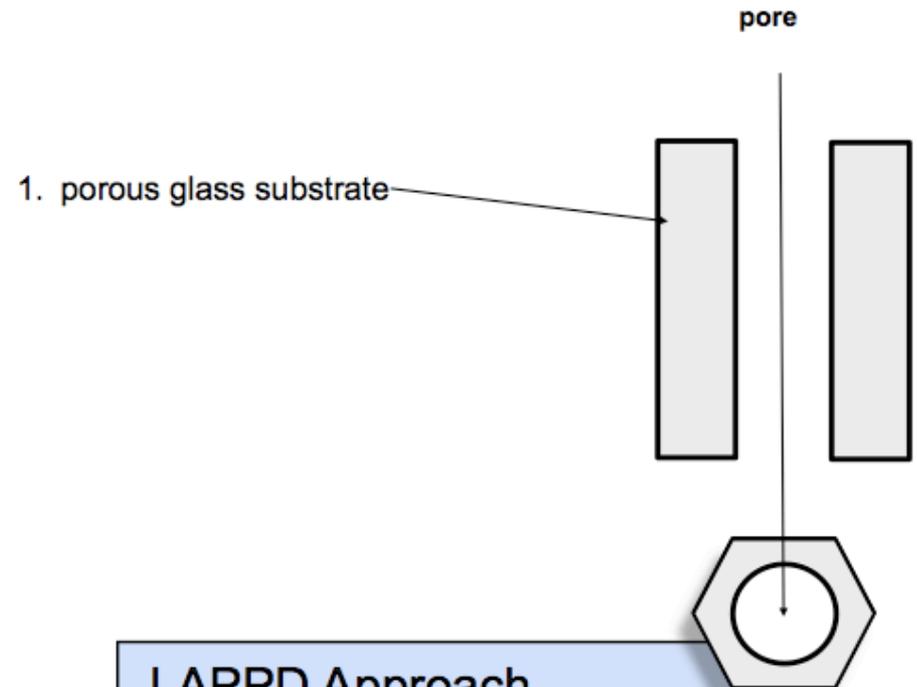
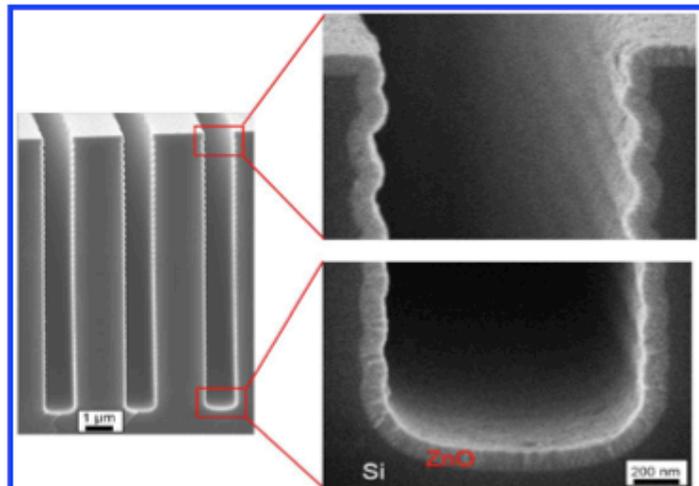
- Thin-films on borosilicate glass
- Glass vacuum assembly
- Simple, pure materials
- Scalable electronics
- Designed to cover large areas

Conventional MCPs:

- Conditioning of leaded glass (MCPs)
- Ceramic body
- Not designed for large area applications

Conventional MCP Fabrication

- Pore structure formed by drawing and slicing lead-glass fiber bundles. The glass also serves as the resistive material
- Chemical etching and heating in hydrogen to improve secondary emissive properties.
- Expensive, requires long conditioning, and uses the same material for resistive and secondary emissive properties. (Problems with thermal run-away).

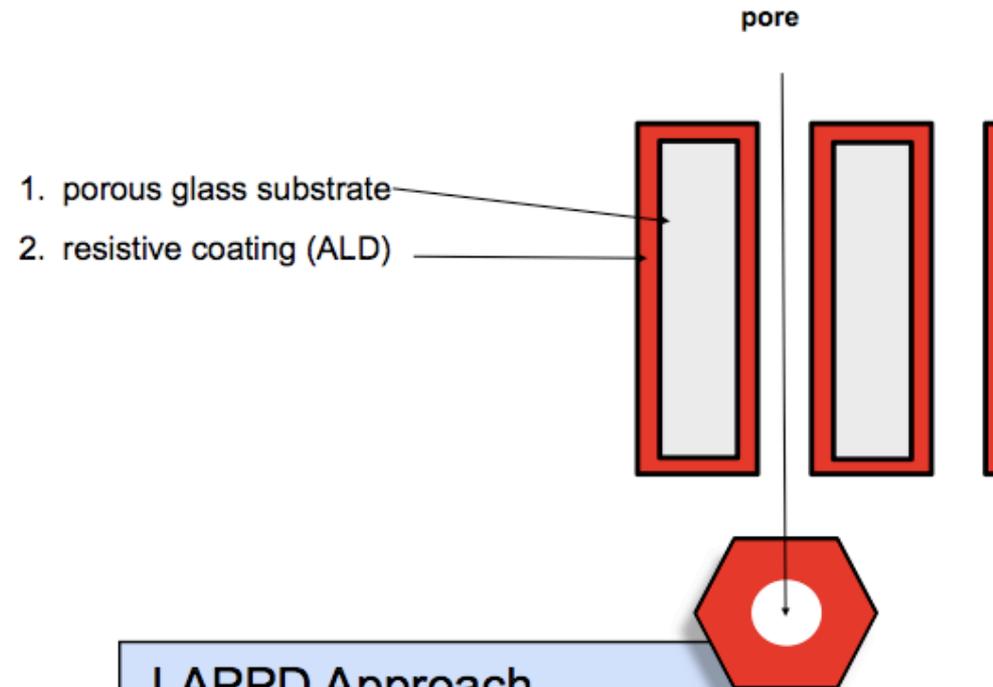
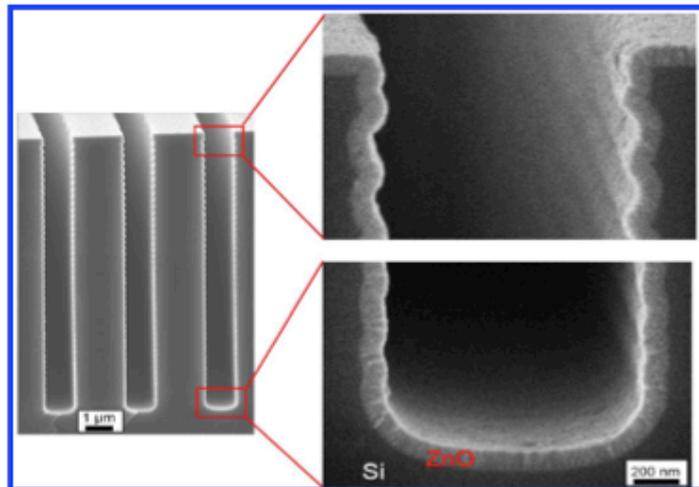


LAPPD Approach

- Separate out the three functions
- Hand-pick materials to optimize performance.
- Use Atomic Layer Deposition (ALD): a cheap industrial batch method.
- ALD is diffusive, conformal and allows application of material in single atomic monolayers

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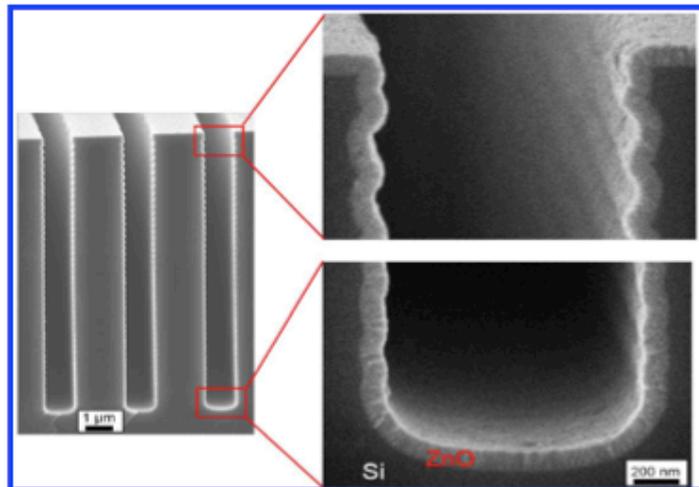


LAPPD Approach

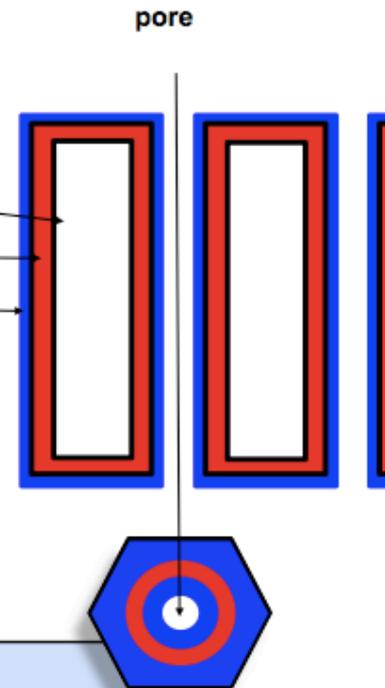
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1. porous glass substrate
2. resistive coating (ALD)
3. emissive coating (ALD)

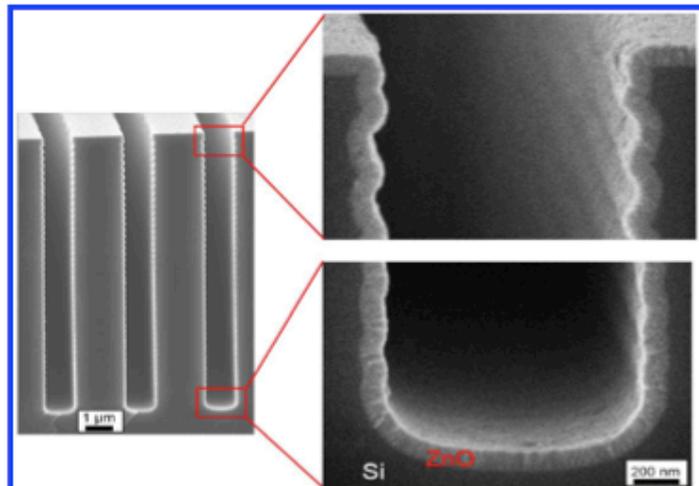


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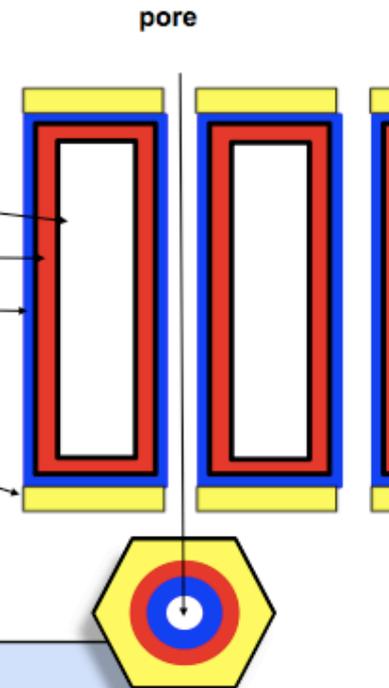
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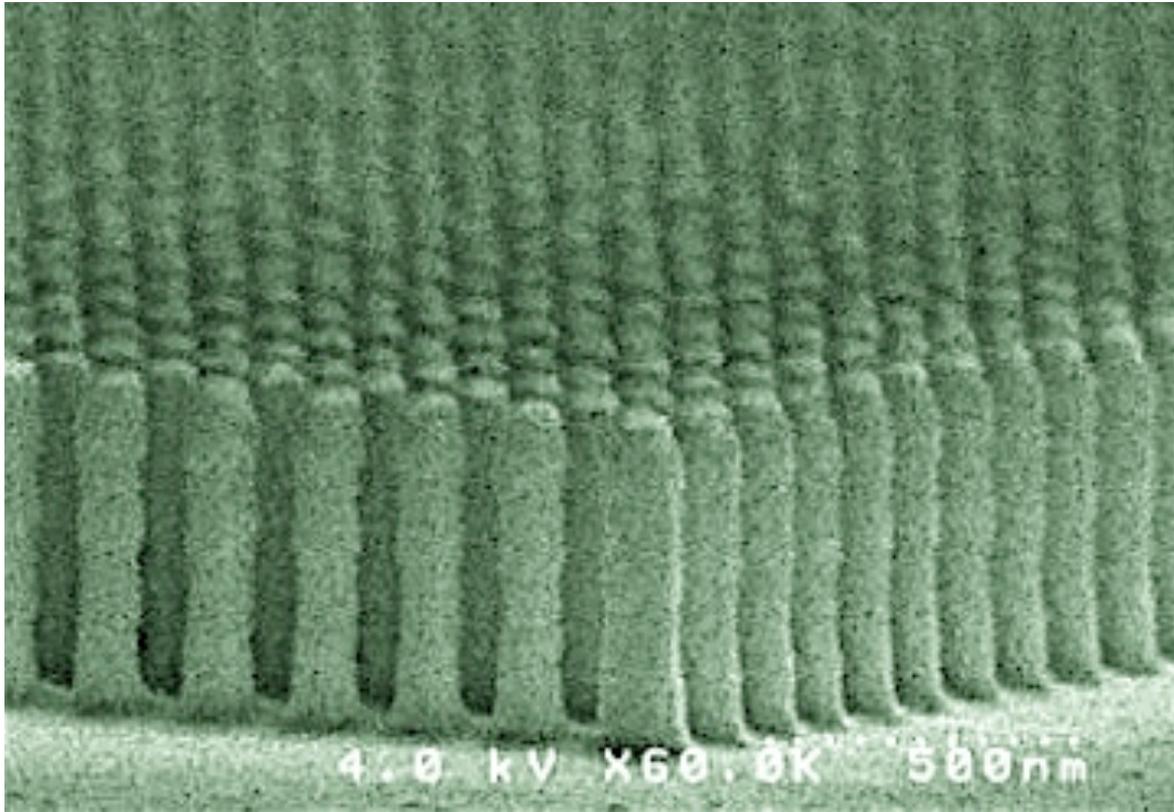
1. porous glass substrate
2. resistive coating (ALD)
3. emissive coating (ALD)
4. conductive coating (thermal evaporation or sputtering)



LAPPD Approach

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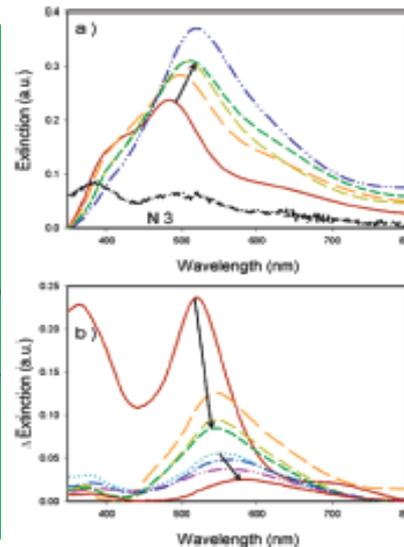
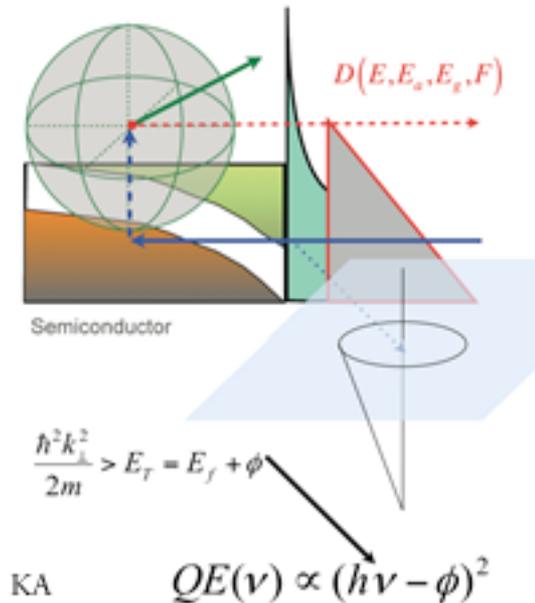
Separating Functionality



When you separate structure from other chemical processes, interesting new ideas are possible.

Photocathodes are an example of a technology, often taken for granted, where there is a lot of room to understand the basic underlying physics.

Material scientists and HEP folks are making strides in understanding the basic materials and optimizing them for ultra-high QEs.



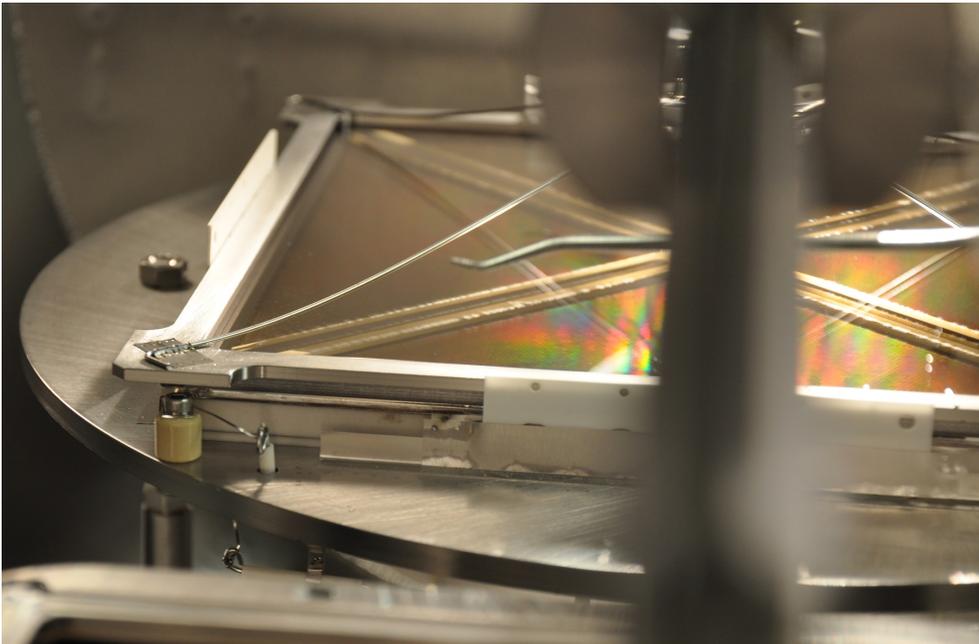
See, for example:

Second Workshop on Photocathodes – U Chicago

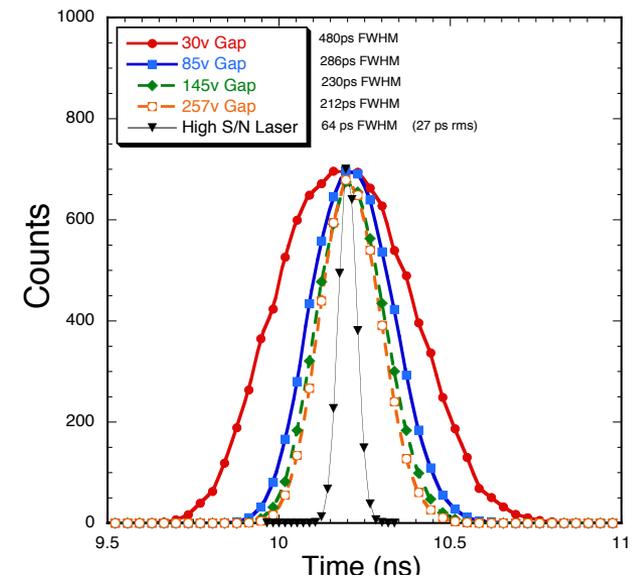
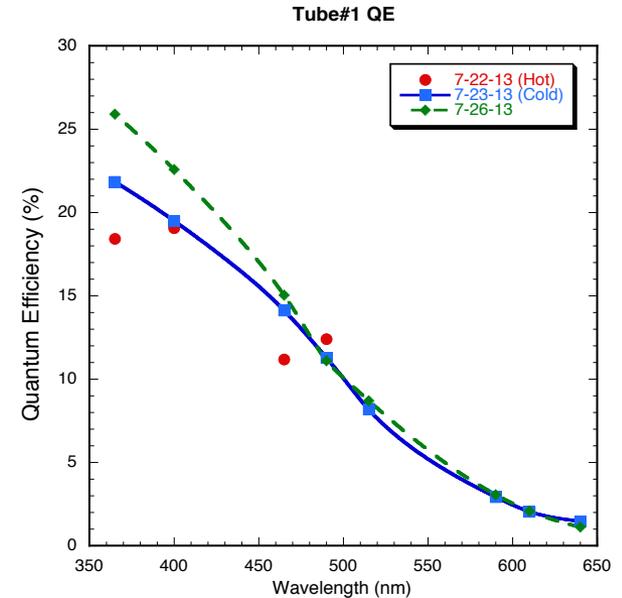
https://psec.uchicago.edu/workshops/2nd_photocathode_conference/

Postscript/News Flash!

- First complete LAPPD (with photocathode) has been sealed at Berkeley SSL
- Will be brought to air, any day now...possibly before Snowmass ends.



Tube with window hot indium seal completed



Importance of Cross-pollination



Reaching out to other communities can produce an unstoppable force.

Importance of Cross-pollination

